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Forest lands in California, the majority of which are in the middle to high elevation foothills and mountains, produce a diverse array of resources such as water, timber, native vegetation, fish, wildlife, and livestock, and outdoor recreation. However, the water produced by these forests has economic value that equals or exceeds that of any other forest resource (Krieger 2001; CAL FIRE 2003). Most of California's major rivers and a substantial portion of its runoff originate in these forests; therefore, most of California's major water development projects are tied strongly to forested watersheds.

Forest management activities can affect water quantity and quality. This strategy focuses on forest management activities, on both public and privately-owned forest lands, whose goals specifically include improvement of the availability and quality of water for downstream users.

Water rights for groundwater in most areas of California are assigned to overlying landowners and reasonable use is unregulated. In contrast, surface water rights, which are managed and enforced by the State Water Resources Control Board (SWRCB), are a complicated mixture of riparian, appropriative, and adjudicated rights. The U.S. Department of Agriculture Forest Service (USFS) uses federal reserved, appropriative, riparian, and overlying adjudicated water rights to manage forest lands. A large percentage of water flowing from forests is appropriated by state and federal water projects, municipal water agencies, irrigation districts and hydropower companies, many of which are fully appropriated. A list of fully appropriated stream systems for California is available on the SWRCB Web site: http://www.waterboards.ca.gov/waterrights/water_issues/programs/fully_appropriated_streams/.

Water quality in California is protected by the SWRCB and nine Regional Water Quality Control Boards (Regional Boards). The Regional Boards regulate compliance with the federal Clean Water Act through designation of beneficial uses, development of numeric and narrative water quality objectives, water quality control policies, basin plans, basin plan prohibitions, issuance of various types of permits, and enforcement actions. The SWRCB prepares lists of impaired water bodies every two years, as required by Section 303(d) of the Clean Water Act. In addition to listings of threatened or endangered fish and wildlife species by the California Department of Fish and Wildlife, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service, these impaired water body listings have greatly influenced forestry practices on non-federal lands during the past decade (Cafferata et al. 2007b).

Forest Ownership and Management in California

California has more than 30 million acres of forested lands (CAL FIRE 2003; Christensen 2008), which are located primarily in the major mountains of the Coast Ranges, Klamath Mountains, Cascade Range, and the Sierra Nevada. Forest lands in California are owned and managed by a wide array of federal, state, tribal, and local agencies, non-governmental organizations, and private companies, families, and individuals (Table 23-1), each of whom has a different forest management strategy with different goals and constraints.

PLACEHOLDER Table 23-1 Acres of Forest Land by Ownership in California

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

The largest public forest landowner in the state is the USFS, which owns and manages 18 National Forests in California. California's National Forests were established under the Organic Act of 1897, which specifically states that a primary purpose of these lands is to "secure favorable conditions of water flow." U.S. Secretary of Agriculture Tom Vilsach emphasized the role of the USFS in protecting water sources in his remarks made on August 14, 2009:

> "We must work and must be committed to a shared vision, a vision that conserves our forests and the vital resources important to our survival while wisely respecting the need for a forest economy that creates jobs and vibrant rural communities. Our shared vision must begin with a complete commitment to restoration. Restoration, for me, means managing forest lands first and foremost to protect our water sources while making our forests far more resilient to climate change."

The USFS Pacific Southwest Region manages roughly 20 million acres in California for multiple uses including, among other things, timber and livestock production, mineral production, and outdoor recreation (USDA Forest Service 2007). Despite their name, these National Forests include a wide variety of ecological communities, including subalpine and montane forests, alpine shrublands, chaparral, desert, and wetlands. Timber on National Forests is produced through commercial timber sales to private contractors and livestock are grazed under a permit system. Environmental issues related to resource management on National Forests are addressed under the National Environmental Policy Act (NEPA). Resource management on each National Forest is guided by a Land and Resource Management Plan (LRMP), which is revised and updated roughly every fifteen years. The content and format of LRMPs is governed by national planning rules, which are also revised periodically, with the most recent planning rule completed in 2011. All future LRMPs will emphasize sustainability, restoration, and forest health.

The U.S. Bureau of Land Management (USBLM) manages 1,650,000 acres of forest in the state (USDA Forest Service 2008), primarily in the North Coast region. The USBLM is a multiple-use land management agency that produces timber through commercial sales and manages livestock grazing through a permit system. Environmental issues related to resource management on public lands administered by the USBLM are addressed under NEPA.

The National Park Service (NPS) manages 1,287,000 acres of forest in 23 units in California (USDA Forest Service 2008). Unlike the USFS and USBLM, the NPS is not a multiple-use management agency, but instead has a mission to preserve natural and cultural resources specifically for public enjoyment and scientific purposes. Commercial timber harvests and livestock grazing are not allowed in national parks, although vegetation may be managed for forest health and fire protection purposes. Pack stock grazing is allowed.

Commercial timberlands (forests used or suitable for producing timber) comprise 16.6 million acres of forest land across the state (CDF 2003), nearly half of which is in non-federal ownership. More than 5 million acres are zoned for timber production and are primarily managed by large, industrial landowners

(CDF 2003), with the remaining non-federal timberlands owned primarily by small non-industrial landowners with a wide range of management objectives. State Demonstration Forests include about 71,000 acres statewide (CAL FIRE 2013). Timber harvesting on non-federal forest lands is regulated by the California State Board of Forestry (BOF) and the California Department of Forestry and Fire Protection (CAL FIRE). The BOF adopts regulations that CAL FIRE has enforced on the ground since 1975. Timber production is the primary use of privately-held forests, but some company-owned forest lands are used for livestock grazing and permitted outdoor recreation, including fishing and hunting. In addition, with the passage of recent climate change legislation (AB 32), some forests are likely to be managed to enhance carbon sequestration and provide offsets to greenhouse gas emissions (GHG).

Urban forestry, although geographically distinct from wildland forests, offers important benefits for water resources and mitigation of climate change. Urban forests are managed by municipal parks and public works departments, as well as by many private organizations and individuals. Trees in urban environments provide more than just aesthetic benefits, including interception of rainfall, reduction of urban runoff, and energy-efficient shade during hot weather.

Forest management agencies also have responsibilities for water-quality protection. The USFS, CAL FIRE, and BOF have been designated by the SWRCB as water quality management agencies for lands that they administer or regulate, and have all implemented water quality management plans that have been certified by the SWRCB. These water quality management programs incorporate Best Management Practices (BMPs) or Forest Practice Rules (FPRs) that are designed to prevent adverse impacts to water quality from forest management activities, and include monitoring programs to evaluate BMP/FPR implementation and effectiveness. The USFS water quality program also includes restoration of “legacy” sources of pollution.

Extensive monitoring of California’s FPRs for protecting water quality on non-federal timberlands was conducted from 1996 through 2004 by two State programs—one using independent contractors acting as third party auditors to collect field data, and one using CAL FIRE forest practice inspectors (Cafferata and Munn 2002; Ice et al. 2004; Brandow et al. 2006). Together, these projects inspected more than 600 randomly selected timber harvesting plans (THPs) that had gone through one or more over-wintering periods after the completion of logging. Both projects found that hillslope surface erosion features were almost always associated with improperly implemented forest practice rules on forest roads and at watercourse crossings, and that watercourse and lake protection zones (buffer strips) retained high levels of post-harvest canopy and surface cover, which prevented harvest-related erosion. Approximately 20 percent of stream crossings were found to have significant problems with forest practice rule implementation or effectiveness. Overall, California forest practice rule implementation rates have been found to be among the highest of any of the Western states, and when properly implemented, these practices have been found to be highly effective in preventing hillslope erosion features (Ice et al. 2004; Council of Western State Foresters 2007; Ice et al. 2010).

The USFS reported on monitoring data collected from 2003 through 2007 at roughly 2,900 randomly located sites to evaluate the implementation and effectiveness of its water quality BMPs on National Forests (U.S. Department of Agriculture Forest Service 2009). The BMP Evaluation Program uses 29 different onsite monitoring protocols to evaluate BMP implementation and effectiveness, with the majority related to timber and engineering practices. Overall, 86 percent of the BMPs evaluated were rated as correctly and fully implemented, and 93 percent of these were rated as effective in protecting water quality. Among all evaluations, 98 percent were found to have no significant adverse effects on water quality. The protocols most likely to be associated with measurable adverse water quality effects (percentages of BMPs with measurable effects higher than 15 percent) were developed recreation sites, road stream crossings, and water source development. These protocols also were found to have relatively low effectiveness when implemented.

Effects of Forest Management on Water Supply

The scientific evidence for relations between forests and water supply, however, has been inconclusive (Dudley and Stolton 2003; Troendle et al. 2007). Research has shown that forests have had a limited role in flood protection and variable effects on total water yields and base flows (Ziemer and Lisle 1998; U.S Department of Agriculture Forest Service 2000; Calder et al. 2007; Moore and Wondzell 2005; National Academy of Sciences 2008). In contrast, several studies have convincingly demonstrated that forests protect water quality by reducing erosion and removing runoff pollutants (for example, U.S. Department of Agriculture Forest Service 2000; Dudley and Stolton 2003; Calder et al. 2007). Forested watersheds in interior California are the location of California's winter snowpack. In contrast to rainfall that runs off rapidly, these snowpacks store enormous quantities of water through the winter wet season and release this stored water as spring and early summer snowmelt runoff, when it is most needed by humans and the environment, reducing the need for additional downstream dams and reservoirs.

Predicted climate changes for California are likely to have large impacts on forest ecosystems and on water supply in the near future. Climate model predictions suggest that there will be a shift in precipitation that results in more rainfall and less snowfall at mid-elevations in the Sierra Nevada (see http://www.water.ca.gov/climatechange for more detail), and in fact, more rapid spring snowmelt in the Sierra Nevada is already occurring (Peterson et al. 2008). This predicted shift toward less snow is critically important for water management because the existing water development infrastructure is designed to exploit streamflows that are driven by gradual releases of water during snowmelt. If snow is replaced by rain at mid-elevations, then winter flood peaks are likely to become larger and more frequent, and reservoir storage is likely to be exceeded in wet months when demand is low, Correspondingly, summer stream base flows will be lower in dry months, when demand is high. These climate-driven impacts could lead to proposals for new dams and reservoirs on forest streams with their resulting environmental impacts, as well as for additional off-site reservoirs.

Climate change also directly affects forests through increased drought stress, which makes trees more vulnerable to insect attack, with the resulting increased rates of tree mortality influencing wildfire frequency, size, and severity. These stresses on forests will affect their capacity to naturally regulate streamflow and buffer water quality. Many streams that are now perennial are likely to become intermittent with the resulting loss of riparian zones, aquatic habitats, and other beneficial uses of water that depend on perennial flows.

The importance of forest management for protection and improvement of water resources has increased due to concerns about increased demand for water, extended drought, economic and environmental costs of new water-supply infrastructure, effects of water transfers on endangered species, and effects of climate change on water supply and hydropower generation. Although current scientific consensus supports the role of forests as protectors of water quality, the potential for improvements in the availability of water through active forest management should not be overlooked (Bales et al. 2011). The following sections discuss forest management actions that have potential for improving water resources in California. (Discussion of an additional management action, snow fences, is in chapter 27, Watershed Management in this volume.) Forest management activities that alter streamflow regimen to benefit downstream water users (primarily by altering the timing of streamflow peaks) may be more successful than attempts to increase total water yield.

Meadow Restoration and Groundwater

Meadow wetlands are alluvial landforms located in areas of level topography that are flooded or saturated during the growing season, typically along streams in the mountainous areas of the state. In contrast to the surrounding terrain, meadows have gentle slopes and support flood-tolerant herbaceous plants and shrubs rather than conifers (Ratliff 1985). These communities are a minor part of the landscape, but they provide disproportionally important ecological services by contributing to downstream water quality and flow, attenuating floods, and harboring wetland-associated biodiversity. Geologic factors that favor meadow formation have caused most of California's meadows to be located in the Sierra Nevada, which has more than 10,000 meadows comprising a total of roughly 300,000 acres (USDA Forest Service 2001).

In meadows with intact vegetative cover, the streams that feed the wetland flow in shallow, meandering channels that allow high flows to spread across the meadow surfaces, saturating soils, depositing suspended sediments, and recharging meadow aquifers (Wood 1975). Meadows with intact vegetative cover act as natural reservoirs, storing and releasing snowmelt and rainfall runoff that passes over and through fine-grained, sod-covered meadow deposits. Meadows are often considered to be "sponges" that absorb and release water. This analogy is appropriate for meadows that are supplied by streams and local snowmelt. Meadows that are supplied by groundwater flowing through surrounding hillslopes and underlying fractured bedrock, however, may more accurately be characterized as "valves" that regulate the discharge of regional groundwater as it flows through relatively low-permeability, organic-rich, fine-grained alluvium. Although scientific evidence is not conclusive at this time, meadows may attenuate flood peaks and prolong dry-season base flows (Liang et al. 2007; Tague et al 2008), potentially increasing available water for downstream farms, communities, and hydropower facilities. The importance of meadows in regulating streamflow is likely to increase as climate change results in a shift from snowmelt to rainfall-dominated runoff at mid-elevations in the Sierra Nevada.

Eroded meadows with incised channels lose their capacity to store and release water (Loheide and Gorelick 2007; Cornwell and Brown 2008; Hammersmark et al. 2008; Tague et al. 2008) because the channels convey and concentrate flood peaks more rapidly than well-vegetated meadow surfaces, and groundwater is drained more rapidly from deeper sections of the substrate profile. The rapid conveyance of runoff aggravates downstream flooding and reduces recharge of meadow aquifers (Liang et al. 2007; Hammersmark et al. 2010), decreasing the amount of water available to sustain streams during dry summer months. In addition, channel erosion in meadows adds to stream sediment loads through bank erosion and headcut retreat, adversely affecting downstream water quality and reservoir capacity (Micheli and Kirchner 2002).

The reduced soil moisture and elimination of surface flooding that is associated with meadow incision leads to changes in the associated plant community to types that have less value and provide fewer ecological services. Drying of meadow soils allows invasion by drought-tolerant brush and conifer species that contribute to heavy fuel loading and add to the risk of catastrophic wildfires (Allen-Diaz

1991; Dwire et al. 2006; Berlow et al. 2002; Loheide and Gorelick 2007). Loss of high quality forage provided by wet-meadow sedges, rushes, and grasses decreases forage value for meadows that are grazed by livestock (Ratliff 1985; Stohlgren et al. 1989). Loss of wetland vegetation reduces habitat area for several rare, threatened or endangered species such as the Mountain Yellow-legged Frog, Willow Flycatcher, and Bell’s Vireo.

By 1940, many of the meadows throughout the Sierra Nevada were eroded by incised channels or gullies, as a result of unrestricted livestock grazing, road building, railroad construction, elimination of beavers, and other causes (Wood 1975; Kattelmann and Embury 1996; Martin 2006). Although current activities are carefully managed to avoid damage to meadows, the effects of earlier practices remain on the landscape and the landscape is unlikely to heal without active restoration (Ratliff 1985). Future disturbances from wildfires, intense storms, and illegal activities could cause further damage that will require restoration.

Meadow restoration is a form of groundwater banking that can provide a wide array of ecological benefits in addition to enhancing water supplies. California’s forests encompass the headwaters of the major rivers within the Sierra Nevada, and include thousands of meadows. A regional approach to meadow restoration could help to meet the state’s need for high quality water and aquatic habitat and help offset the effects of climate change if public consensus on benefits can be achieved.

Like dams, meadow restoration does not create “new” water, but alters the temporal distribution of streamflow so that less water flows downstream during peak runoff periods in the winter and spring when water is not in high demand and more is released during the summer low-flow season when demand is great. Based on the limited available information and a reasonable range of assumptions, meadow restoration in the Sierra Nevada could increase the amount of groundwater retained in meadows by 50,000 to 500,000 acre-feet (af) annually. The wide range in these estimates results from uncertainties in channel depths and specific yields of meadow alluvium. Increased groundwater storage in meadows would be likely to enhance summertime instream flows (Liang et al. 2007), a function that will become increasingly important because of climate change, but the extent to which groundwater retention might extend or increase summer baseflows has not yet been determined.

Meadow restoration is likely to be most effective in prolonging the duration of base flows in meadows that act as “valves” in regional groundwater flow systems (Wood 1975; Hill 1990; Jewett et al. 2004; Hill and Mitchell-Bruker 2010). On the basis of bedrock permeability (Peterson et al. 2008), meadows that function as “valves” are more likely to be found in volcanic and weathered granitic watersheds than in glaciated granitic watersheds.

The USFS manages many Sierran meadows on National Forest System lands, and has been actively working since 1930 with partner agencies and organizations to restore the hydrologic, geomorphic, and biologic functions of meadows damaged by channel downcutting. Several projects using the “plug and pond” approach for example, (Tague et al. 2008; Hammersmark et al. 2008) have been successfully implemented in the past 10 years in the Shasta-Trinity, Plumas, Tahoe, and Sequoia National Forests, and the Lake Tahoe Basin Management Unit. The “plug and pond” method involves ‘plugging” incised channels in meadows by excavating a small upstream “pond” to provide the substrate for the plug. Typically, a series of multiple ponds and plugs are installed along a stream reach through a degraded meadow. The plugged channel routes surface flows over the meadow surface, which reconnects the stream with its floodplain, raises meadow water tables, and prevents headcut migration.

"Plug and pond" meadow restoration has become more controversial since 2009, when concerns by both environmental advocacy groups and downstream irrigators became widely known. A major issue for project opponents is the potential for restored meadows to retain groundwater that is either lost to increased evapotranspiration by meadow plants or held indefinitely in subsurface storage. The Boards of Supervisors of Plumas and Sierra Counties have passed resolutions requiring proponents of meadow restoration projects to consider and mitigate adverse effects on downstream water rights holders. The State Water Resources Control Board investigated two complaints related to meadow restoration projects in the northern Sierra Nevada, and concluded that project proponents were not required to obtain water rights for the projects. As a result of legal and political opposition, the pace of meadow restoration has slowed and its long-term outlook will likely be affected by new scientific information that documents the hydrologic effects of meadow restoration.

Management of restored meadows is key to long-term persistence of the site as a meadow community. The saturated soils that are the goal of meadow restoration should exclude establishment of new conifer seedlings and should cause dieback of existing encroaching conifers, which will generally be unable to survive the wet conditions. Land managers will need to consider whether removal of these trees is warranted. In most cases, livestock grazing has been temporarily halted during and after restoration projects. Permanent exclusion of livestock is not generally necessary to protect meadow resources if pastures are effectively managed to limit cattle numbers, distribution, and seasons of use.

Riparian Forests

Riparian forests are forested lands, usually in narrow linear strips, that are located immediately adjacent to streams, lakes, or other water bodies. These communities occupy a transition zone between aquatic and terrestrial habitats, and are distributed in complex patterns that are responses to geomorphology, annual flood timing and extent, soil moisture, and plant competition. The boundaries between riparian and upland forests are not always distinct, and the width of a riparian forest strip varies laterally throughout the channel network and is strongly influenced by geomorphology (Naiman et al. 1998).

Unfortunately, riparian forests are prone to invasion by noxious non-native plant species that reduce the value of the community to humans and wildlife. In recognition of the central role played by riparian forests in the landscape, the California Forest Practice Rules require that the beneficial functions of riparian zones and populations of native aquatic and riparian-associated species must be maintained where they are in good condition, protected where they are threatened, and restored where they are impaired insofar as is feasible.

Forested floodplains are zones of very high biological diversity, generally harboring the highest biodiversity of both terrestrial and aquatic organisms within the watershed landscape (Naiman et al.1998) and providing important habitat for wildlife (Kattelmann and Embury 1996; Ligon et al. 1999). Riparian floodplains play large roles in forested watersheds that are disproportional to their small area in the landscape. The high surface roughness of forested floodplains has large effects on stream hydrology by reducing floodwater velocities and spreading flood flows across a larger area of the floodplain. The retention and slowing of floodwaters across a wider area allows floodwaters to recharge alluvial groundwater aquifers and attenuates downstream flood flows (Cafferata et al. 2005).

Studies have shown that riparian forests can improve water quality. Riparian forests contribute to reductions in sediment, nutrient, and pesticide loads of surface runoff through physical and biological processes, reducing these inputs to watercourses. Canopy shading by riparian trees reduces stream water temperatures, which is important for many fish species that are adversely affected by elevated water temperatures.

Riparian forests are protected on federal, state, and private timberlands by regulating areas near streams as riparian buffers, within which management actions such as timber harvesting and road building are restricted. The width of riparian buffers, and restrictions on management activities within them, are based largely on land ownership. Within the National Forests, riparian buffer widths vary based on planning province standards and guidelines, with riparian protection being most extensive for the six National Forests that operate under the Northwest Forest Plan. Provincial refers to the three major planning provinces used in the National Forest System in California — the Northwest Forest Plan province, the Sierra Nevada Framework province, and the Southern California province.

Even with these protections, the extent of riparian forest is greatly diminished from its historical extent, particularly in lowland valleys where riparian forests have been converted to orchards and other agricultural uses. In the Central Valley, riparian forests historically covered more than 900,000 acres but presently account for less than 100,000 acres (Barbour et al. 1993).

Unmanaged riparian stands can be sources of rapid fire migration in fire-prone landscapes (Murphy et al. 2007). Fuels reduction within riparian buffers may be needed in some cases to reduce threats of catastrophic wildfires, particularly in the interior parts of California (U.S. Department of Agriculture Forest Service 2007; Van de Water and North 2011). Goals for this type of work include creating fire resilient forests, promoting reduced fire intensities, and retaining functional aquatic and riparian habitat following a wildfire. Removal of trees from riparian buffers remains highly controversial (Welsh 2011), and forest management and regulatory agencies are carefully evaluating monitoring data, particularly with regard to the use of mechanical equipment in streamside zones (Norman et al. 2008).

Some riparian forests are used for livestock grazing, usually within allotments that consist mostly of upland pasture. The availability of water and forage make riparian areas attractive to livestock, which can damage riparian forests through trampling, browsing, and contamination of streams with fecal material (Campbell and Allen-Diaz 1997). BMPs for range management and National Forest standards and guidelines for riparian management are designed to protect riparian forests from damage by livestock. Although exclusion of cattle may be needed during and immediately after restoration of riparian forests, grazing strategies that minimize impacts on riparian forests through restrictions on livestock numbers, distribution, and season of use can be used to eliminate the need for permanent fencing.

Riparian forests are primarily a result of the interplay of hydrologic processes occurring in the stream, floodplain, and groundwater, and alteration of these processes can have dramatic effects on riparian plant communities. Many of the tree and shrub species that dominate California riparian forests (e.g., cottonwood, willow) are dependent for regeneration on the annual flooding and exposure of a floodplain because their seeds can only germinate in moist, emergent areas that have been scoured of vegetation –

conditions that occur only after high water events. Dominant riparian tree species often have little or no tolerance for dry conditions and require the reliable source of moisture supplied by the streamflow. Some riparian plant species have shallow root systems and can only utilize water in shallow areas of the soil profile or in the stream channel directly, while other species have roots that penetrate deeper into the soil profile and utilize available groundwater, which is typically replenished by streamflow infiltration. Species distributions are further affected by patterns of sediment deposition caused by stream hydrologic processes. Riparian plants, particularly trees, also affect stream hydrology, in turn, by contributing large woody debris that creates pools, and affect channel morphology through the actions of roots.

Riparian forests, therefore, may affect and be effected by channel incision and groundwater storage in much the same ways as meadows. The water quantity and quality benefits provided by riparian forests can be preserved and enhanced through actions that maintain natural channel geomorphology. Thus, protection of riparian forests depends heavily on effective management of upland watersheds to prevent excessive runoff and sedimentation, as well as control of non-native invasive species.

Vegetation Management for Water Supply

Management of forest vegetation to improve water supplies has a long history in the western United States. Early efforts attempted to reduce transpiration or increase snowpack by removal of trees, most ending with limited success (Ziemer 1987). Changes in water yields resulting from vegetation management are highly variable and difficult to measure, with indications that treatments must remove at least 20 percent of the vegetation to have a measurable effect on streamflow (Troendle et al. 2007). Computer simulations by Troendle et al. (2007) indicate that every twelve acres of forest thinning (fuels reduction) could theoretically produce an increase of 1 af of runoff. They suggested that the water yield response to large-scale forest thinning in the northern Sierra Nevada forests would be short-lived with a single treatment, perhaps only 15 years, but that an active management program could result in subtle increases in water yield. Some studies have provided limited evidence that measurable water-yield increases have occurred in larger watersheds in the past in response to vegetation removal. For example, Blanchard (1962, as cited by Zinke 1987) investigated the cumulative effect of 30 years of logging on the South and Middle Forks of the Mokelumne River in the central Sierra Nevada. He reported that between 1930 and 1961, approximately 40,000 acres of forest were logged and that water yields from these watersheds gradually increased during that time period.

Innovative approaches that utilize selective thinning of younger, smaller trees show some promise for limited improvement in streamflow regimen, as well as reducing fuel loading and increasing carbon sequestration (Troendle et al. 2007; E. Holst, Environmental Defense Fund, written communication, 2007). Bales et al. (2011) report that their preliminary estimates based on average climate information suggest that treatments in the Sierra Nevada that would reduce forest cover by 40 percent of maximum levels across a watershed could increase water yields by about 9 percent. These treatments, however, also have potential to increase surface runoff and erosion from disturbed soils (Cram et al. 2007).

Fuels/Fire Management

Wildfire Impacts on Watershed Resources

Wildfires affect water resources by removing vegetation and altering soils and ground cover, with the magnitude of post-wildfire impacts being dependent on burn severity (Ice et al. 2004; Neary et al. 2005;

Moody et al. 2008). These changes have large implications to water resources through their effects on transpiration rates, water infiltration rates, rates and magnitudes of erosion, peak and base streamflows, and total water yield.

In the absence of human intervention, wildfires were regular occurrences in California forests, where relatively frequent fires prevented large accumulations of fuel materials and fires were generally fast-moving, low-intensity, and did not kill established trees. Active fire suppression since the 1920s has led to a situation in much of California where forests have developed high fuel loads that greatly increase the risk of catastrophic high intensity, stand-replacing fires that kill all vegetation, generate large volumes of eroded soil and ash (Robichaud 2000; Reneau et al. 2007; Rulli and Rosso 2007; Carroll et al. 2007), and cause large quantities of mobilized nutrients such as nitrate nitrogen, ammonium nitrogen, and phosphate phosphorus to move into stream runoff (Miller et al. 2006).

The removal of forest canopies that is associated with high burn severity temporarily reduces transpiration and interception losses. Consequently, streamflows increase until vegetative re-growth increases transpiration to or above pre-fire rates (Driscoll et al. 2004), and yields of water from a burned watershed are increased.

In areas with heavy fuels (typically forests and chaparral that have not burned or been treated to reduce fuels for many years) intense wildfire can lead to development of hydrophobic soil layers, particularly in dry coarse-textured soils, that dramatically reduce surface water infiltration rates. The impermeability of hydrophobic soil layers, in conjunction with the lack of ground cover remaining after fires, can lead to increased erosion and early-season surface runoff (Neary et al. 2005; Onda et al. 2007; Moody et al. 2008), causing greater transport of sediment to downstream reservoirs and adverse impacts to water treatment and conveyance facilities (Neary et al. 2005; Moser 2007).

Post-wildfire erosion is highly variable, difficult to predict, and highly dependent on the size, number, and intensity of storm events during the first one-to-two winters following the fire. Increases in erosion are typically two or more orders of magnitude for intense wildfires the first winter after burning (Robichaud et al. 2010).

Peak streamflows are increased after intense wildfires, but the magnitude of this increase varies greatly by size of the watershed and its location in California. Changes in post-wildfire peak flows are greatest in small watersheds (e.g., <250 acres) since stormflow response of small basins is controlled primarily by hillslope processes, including infiltration rate, which, in turn, are affected by wildfire (Neary et al. 2005). While data are limited, peak flow increases are likely to be higher in Southern California chaparral-covered basins than in Northern California coastal and snow-dominated watersheds (Robichaud et al. 2000; Neary et al. 2005). Peak flow increases in Southern California are commonly predicted to increase two to three times following intense wildfire for flows that occur with a recurrence interval of two years or greater (Rowe et al. 1949; Moody and Martin 2001).

Although increased water yield is a potential impact of large, intense wildfires, it is generally not significant. Where 75 to 100 percent of the vegetative cover is removed, runoff may increase from 0.1 af per acre burned in watersheds receiving 15 inches of mean annual precipitation, to 0.8 af per acre burned for watersheds receiving 40 inches of mean annual precipitation (based on Turner 1991). In forested areas, water-yield increases are minimal until basal area loss to fire exceeds 50 percent (Potts et al. 1989).

The additional water yields that result from catastrophic wildfires are generally considered to have little value for water supply and hydroelectric energy generation. Almost all of the additional runoff occurs during the wet season and must be regulated for dry season use by surface reservoir storage (Ziemer 1987). Typically, flows increase during large storm events when water is intentionally allowed to pass through reservoirs owing to flood management concerns. The occasional short-term positive gains from increased water yield are more than offset by the frequent short- and long-term negative impacts of increased peak flows, increased sedimentation, and decreased water quality (California State Board of Forestry 1996).

Increases in suspended sediment and turbidity are usually the greatest impact to water quality following intense wildfire, besides the direct and indirect effects fires can have on water delivery infrastructure. While data are scarce, post-wildfire turbidity values are often expected to exceed drinking water standards for water supplies. Post-fire sediment concentrations are generally highest the first year after the fire, but the extent of sediment mobilization depends on the size of the storms following the fire (Fiori 2005). Increased sedimentation can severely impact aquatic habitat, including that for state and federally listed anadromous salmonids in Northern California. Intense wildfires also remove streamside vegetation, causing water temperatures to rise (Amaranthus et al. 1989; Mahlum et al. 2011). Increased water temperatures can adversely fish species by increasing pathogens and algae, and by decreasing amount of dissolved oxygen and aquatic organisms available to fish (Amaranthus et al. 1989).

Nitrogen is the most important nutrient affected by fire, with the amount of change in nitrogen in a burned area being directly related to the magnitude of soil heating and fire severity, and proportional to the amount of organic matter destroyed (Neary et al. 2005). Intense wildfire can lead to significantly increased nitrogen loads in stream water, particularly in Southern California where post-wildfire concentrations of nitrogen in streams as soluble nitrate have been found to exceed drinking water standards (Meixner and Wohlgemuth 2004), but not in Northern California (Cohen 1982).

Fuel Treatments to Reduce Wildfire Impacts on Watershed Resources

Fuel hazard reduction projects have been shown to reduce the risk of catastrophic crown wildfire (Martinson and Omi 2003; Omi and Martinson 2004), reducing both the severity and frequency of wildfire (Elliot 2010). Fuel reduction projects can have adverse effects on water quality (McClurkin et al. 1987; Wondzell 2001; Grace et al. 2006), but these effects are generally minor and temporary, and are far exceeded by the adverse effects of catastrophic wildfires (Benavides-Solorio and McDonald 2001; U.S. Department of Agriculture Forest Service 2005; Madrid et al., 2006; Hatchett et al. 2006; Cram et al. 2007; Robichaud et al. 2007; Gokbulak et al. 2008). The adverse impacts of wildfire are generally much greater per unit of affected area than the impacts of fuel reduction projects, and also affect much larger areas than are included in fuel reduction treatments. Prescribed fire, thinning, and mastication are the main types of fuel reduction methods used to decrease the intensity, extent, and negative consequences of wildland fire in California. Prescribed herbivory (e.g., cattle and goat grazing used to maintain fuel breaks) is an additional option that is sometimes used. The most effective fuel reduction treatments for decreasing the spread and intensity of wildfires have been combinations of mechanical treatments and prescribed burning (Stephens and Moghaddas 2005; Dailey et al. 2008). Fuel management treatments are generally required every 10 to 20 years to maintain their effectiveness in reducing the risk of catastrophic wildfire (Robichaud et al. 2010).

In general, hydrologic impacts from prescribed burning are small, since these fires are usually low intensity (Beschta 1990; Heard 2005; Robichaud et al 2010). Prescribed burns in chaparral typically generate more soil heating than prescribed burns in either grasslands or forests and produce more sediment than with other vegetation types (10-30 percent of the sediment yields after high severity wildfires) (Wohlgemuth 2001). Prescribed fires in chaparral that kill a significant proportion of the mature canopy or expose more than 35 to 50 percent of the soil can have a significant, detectable effect on annual water yields lasting 8-10 years, but with little detectable impact on downstream water storage reservoirs (Troendle et al. 2010). Nutrient impacts to water quality associated with prescribed burns is minimal in both forested and chaparral watersheds (Stephens et al. 2004; Meixner and Wohlgemuth 2004).

Commercial thinning operations that remove a significant portion of the overstory canopy have the potential to elevate stream sediment loads when the proportion of bare soil is high (Robichaud et al. 2010). Roads associated with commercial thinning operations usually are the largest sediment source associated with commercial timber operations (MacDonald et al. 2006). Only relatively heavy thinning operations can be expected to increase annual water yields in wetter environments, with no measurable increase in runoff expected from thinning operations that remove less than 15 percent of the forest cover or in areas with less than 18 inches of annual precipitation (Reid 2012; Robichaud et al. 2010). Burning of slash piles often produced with thinning produces intense soil heating at the pile locations and alters soil properties, but very limited movement of nutrients downslope from the piles has been detected (Hubbert et al. 2010).

Hydrologic impacts associated with non-commercial fuel reduction thinning operations that are done to reduce the risk of catastrophic wildfire are small, producing only short-lived impacts to runoff and sediment production. Non-commercial thinning to reduce fuel loads is increasingly being accomplished using masticating machines that mechanically grind, crush, shred, chip, and chop fuel. Woody material that remains following mastication increases the amount of ground cover and substantially reduces erosion potential. While research is limited, mastication appears to be an effective thinning treatment for overstocked timber stands with few negative impacts on soil compaction or soil erosion (Hatchett et al. 2006).

Management Strategies to Reduce Adverse Impacts Associated with Wildfire

Forest management activities to reduce fire severity on California's 18 National Forests are currently administered under the National Fire Plan (NFP) and the Healthy Forest Initiative (HFI). Approximately 70 percent of the 20 million acres of National Forest system lands in California, or 14 million acres, are in need of treatments to reduce fuel loads to natural levels. In all of California, approximately 21 million acres have been designated as high priority landscape for treatment (CAL FIRE 2010a). The USFS and other federal and state agencies are currently treating about 220,000 acres per year in California (approximately half with prescribed burning), while an average of 320,000 acres are burned annually by wildfires (CAL FIRE 2010a). Prior to European settlement (pre-1800), it has been estimated that 4.5 million acres are burned per year on average in California (Stephens et al. 2007)

Firefighting tactics are increasingly being modified to protect water quality and aquatic organisms (National Wildfire Coordinating Group Training Working Team 2004). For example, guidelines in effect since 2000 specify that aerial fire retardant drops are to be avoided within 300 feet of waterways (NIFC 2010). Rapid restoration of areas disturbed by fire suppression actions to reduce erosion potential and protect water quality is routinely included in suppression efforts on both National Forest and non-federal lands in California. Fire control lines, particularly those created by heavy equipment, disturb the soil, increase soil compaction, reduce infiltration, can become sources of sediment if not properly rehabilitated, and can alter runoff patterns (Neary et al. 2005; Backer et al. 2004). Practices used to reduce these impacts include installation of proper drainage structures on firelines and roads, and removal of soil from emergency stream crossings built when constructing firelines with crawler tractors.

Following fire containment, burned areas associated with wildfires greater than 500 acres on National Forest lands are assessed, and high-risk areas with downstream values-at-risk are treated to prevent adverse effects on water quality and other resources (Robichaud et al. 2000). Values-at-risk refers to natural resources such as salmonid habitat and human communities that may be adversely affected by the movement of water and sediment from burned areas.

The USFS uses its Burned Area Emergency Response (BAER) program to prescribe practices to reduce erosion potential, as well as to reduce threats to life and property. Similarly, at the direction of the governor, California's Emergency Management Agency (Cal EMA), Natural Resources Agency, and Environmental Protection Agency (Cal EPA) assemble multi-disciplinary teams when necessary to assess post-wildfire potential impacts to life and property on state and private lands. Commonly specified measures include notification of residents in areas at risk for debris slides and channel-derived debris flows, use of automated precipitation and stream gauges linked to local government response and flood control agencies for early warning for evacuation, road and stream crossing improvements, installation of structure protection devices (e.g., K-rails), and on USFS lands where there are high values-at-risk, such as aerially applied straw mulch, and hydro-mulch (Robichaud et al. 2000; Wohlgemuth et al. 2009). Aerial grass seeding has rarely been used in California after 2000, since it has not been shown to be effective in reducing hillslope erosion and often inhibits native species regeneration (Conard et al. 1995; Wohlgemuth et al. 1998; Beyers 2004). Post-wildfire assessment programs will likely become increasingly important in the future due to projections of higher frequency and intensity of wildfires related to climate change.

Recommendations

It is recommended that watershed protection be enhanced through the strategic placement of fuel reduction projects in high priority water supply watersheds, (high priority water supply watersheds are displayed in Chapter 3 of the *2010 Assessment of California's Forest and Rangelands* [CAL FIRE 2010a]) utilizing existing state and federal cost-share programs on non-federal wildlands (CAL FIRE 2010b). Fuel reduction projects should use: (1) mechanical thinning treatments that limit ground disturbance, particularly on steeper slopes and more erodible soil types (Cram et al. 2007), and include appropriate road design, construction, and maintenance practices, (2) mastication where slope gradient is appropriate, and (3) low severity prescribed fire preserving the litter/duff layer and existing nitrogen levels. Fuel reduction treatments, such as thinning, can reduce the threat of high intensity wildfire, and make California forests more resilient in warmer climates (Bales et al. 2011), as well as providing other ancillary benefits, such as biogeneration of power.

Road Management

Thousands of miles of roads have been constructed through forests in California, primarily to provide access for timber harvest. The 18 National Forests in California alone contain approximately 50,000 miles of forest roads, of which roughly 20,000 miles may no longer be needed for their original purposes

(Dombeck 2007). Private forest lands contain many additional thousands of miles of roads. These are mostly unpaved roads and they can have significant effects on hydrology and water quality through their roles in sediment transport and hydrology when they are improperly designed, constructed, or maintained.

Unpaved roads, particularly those adjacent to streams and road stream crossings, are usually the dominant source of management-related sedimentation in forested environments in California due to surface erosion, gullying, and mass wasting (Cafferata and Munn 2002; U.S. Department of Agriculture Forest Service 2004; MacDonald et al. 2004; Coe 2006; Cafferata et al. 2007a). Excessive sedimentation associated with roads is a concern because of potential negative impacts on stream habitat and water quality from sediment that is discharged either episodically when roads or road-stream crossings catastrophically fail, or chronically from incremental surface erosion. However, a relatively small proportion of the total road length produces most of the road-related sediment delivered to streams (McCashion and Rice 1983; Coe 2006).

Forest roads can have significant effects on hydrology by generating overland flow and intercepting subsurface flow, which increases flood peaks (Jones and Grant 1996) and decreases recession flows. Stream crossings are vulnerable to damage by high flows (Furniss et al. 1998) and can divert streams from their natural channels, resulting in serious erosion and water quality problems (Best et al. 2004).

Roads built to modern standards have reduced impacts to forest streams, but many of the forest roads in California were built decades ago to very low design standards, often in environmentally sensitive locations such as unstable hillslopes and riparian areas. A significant number of older roads are part of the current road network, while others have been neglected and abandoned with no consideration or mitigation of ongoing erosional impacts (Cafferata et al. 2007a). These “legacy” roads are particularly susceptible to catastrophic failure during high magnitude, low frequency storm events, such as the one in 1997 that caused extensive flooding throughout a large part of Northern and Central California (Furniss et al. 1998; Madej 2001).

Many of these adverse hydrologic and water quality impacts of roads can be reduced by upgrading and replacing culverts, outsloping road treads, and installing road drainage structures such as waterbars and rolling dips at appropriate spacing, particularly near stream crossings (Furniss et al. 1991; Weaver and Hagans 1994; Keller and Sherar 2003). Roads no longer necessary for resource management or recreation can be effectively decommissioned by removal of fills at stream crossings and partial or total outsloping of road treads, including cuts and fills (Madej 2001; Cook and Dresser 2007). Road decommissioning can potentially reduce water quality impacts. However, it can be difficult to find roads producing significant impacts that people agree should be decommissioned.

Detailed field surveys are the main tool available to identify the road segments of greatest concern (Weaver et al. 2006; Korte and MacDonald 2007). Public and private landowners in California are actively inventorying their road networks, prioritizing road segments requiring road improvement or decommissioning work, and completing projects. A considerable amount of road upgrade work has been completed to date with both public and private financing. While there are short-term impacts associated with road improvement and decommissioning, particularly at stream crossings, improved operator practices has lessened these effects (Pacific Watershed Associates 2005; Cafferata et al. 2007a), and treatments will reduce the long-term sediment production overall from older roads (Madej 2001).

Illegal Marijuana Cultivation

In the past five years, increased impacts from commercial-scale illegal cannabis growing operations have been documented in forested counties throughout California and particularly in the California coast ranges, both on public and private lands. While largely anecdotal, without specific data on numbers of watercourses affected, the impacts have been well documented with digital photographs taken during law enforcement operations (Giusti 2012).

Illegal growing activities adversely impact watershed resources in three main ways: (1) illegal diversions of water from tributary streams utilize low summer flows required for sustaining state and federally listed anadromous salmonids and other species; (2) illegal grading and road building operations cause surface erosion and slope instability, which produces accelerated sedimentation; and (3) large-scale use of pesticides, fertilizers, and rodenticides adversely impacts water quality.

Typical commercial-scale illegal marijuana gardens found on public land include approximately 7,000 plants, with each large plant using approximately one gallon of water per day (Mallery 2011). This equates to approximately 7,000 gallons of water per day over a period of 3 to 4 months or about 2 to 2.5 acre-feet per year per commercial-scale operation. The 2010 Mendocino County Grand Jury Report estimates that only 10 percent of illegally grown marijuana is confiscated annually. More than 500,000 plants are confiscated in many years. Assuming those years are representative, an estimated 5,000,000 plants are produced annually (G. Giusti, UC Cooperative Extension, Ukiah, written communication).

The greatest impact to water resources by illegal marijuana plantations is often not the absolute size of the diversion, but the size of the diversion in relation to the stream being diverted in that it is not unusual for all of the streamflow from a watercourse to be illegally diverted for irrigation using dams, pumps, and elaborate water distribution systems (Thorsen 2011; Mallery 2011). Use of large off-site water storage devices, such as 50,000 gallon water “bladders”, has also been documented. Water diversion causes early de-watering of intermittent streams during a critical time of year for juvenile fish.

Illegal and unregulated grading operations, including grading that enables marijuana cultivation, have been documented in several North Coast counties and they have been found to have adverse watershed impacts. Illegal grading operations increases suspended sediment concentrations and turbidity in intermittent and perennial fish-bearing watercourses, adversely impacting both macroinvertebrates and anadromous salmonids. The extent of illegal grading and its significance to anadromous fish species is currently unknown, however, since counties lack adequate staff to monitor for illegal and/or improper grading (Harris 2011).

Unregulated pesticide, fertilizer, and rodenticide use is extensive in commercial-scale operations and potentially presents a major problem for water quality (Giusti 2012). Mallery (2011) states that an estimated 1.5 pounds of fertilizer are used for every 10 marijuana plants. A three week-long, multi-agency law enforcement operation on public and private lands in Colusa, Glenn, Lake, Mendocino, Tehama, and Trinity Counties in 2011 removed 5,459 pounds of fertilizer and 149 pounds of pesticides from cultivation sites (U.S. Department of Agriculture Forest Service 2011c). An average 5 acre site can contain 20 pounds of rodenticides, 30 bags of fertilizer, plant growth hormones, insecticides, herbicides, and fungicides as well as other chemicals (Mallery 2011). Unused or abandoned chemicals are typically left on-site and leach into waterways and groundwater aquifers, and gasoline and other petroleum products also produce water quality impacts (Giusti 2012).

While the total number and area covered by illegal commercial-scale marijuana operations is unknown, the fact that they operate outside of laws and regulations governing water diversion and water quality protection indicates that they are producing significant impacts wherever they occur.

Urban Forestry

Trees planted along streets and in city parks, lots, and private residences collectively form urban forests, and urban forestry practices address the maintenance of existing urban trees as well as the planting of new trees in and around cities. Although urban forests are not managed specifically for natural resource production or conservation, they have environmental benefits that extend well beyond aesthetics.

Urban areas in California cover roughly 5 percent (7,944 sq. mi.) of the land base, but support 94 percent of the population (CAL FIRE 2010a). An estimated 15.1 percent of California's urban area (800,000 acres), which is home to almost one-third of the state's population (9.5 million people), is associated with high threats from air pollution and urban heat islands (CAL FIRE 2010a). Urban trees are an important means of mitigating heat and air pollution. As a result, communities throughout California are recognizing the importance of urban trees and have plans to expand urban forests. The need for expanding or enhancing urban forests is substantial, with 372 communities identified as high priority for tree planting in urban areas by the *2010 CAL FIRE Forest and Range Assessment* (CAL FIRE 2010a).

Urban Watershed Forestry

While not part of the wild environment, urban trees contribute to the overall health of a watershed, and their contribution is addressed by the discipline of urban watershed forestry, which is an integration of urban and community forestry and watershed planning. Urban and community forestry focuses on how to manage urban forests for environmental, community, and economic benefits while watershed planning focuses on strategic land use and resource management within a watershed. The integration of these two methods into urban watershed planning recognizes the role trees play in protecting water resources, and is becoming a valuable resource management tool for urban planners.

Tree Cover and Watershed Benefits

Trees in an urban setting provide multiple watershed benefits (Table 23-2), including reduction of stormwater runoff and stream channel erosion, improved soil and water quality, and reduction of air and water temperatures. For example, it is possible for a single tree to contain 100 gallons of water or more within its leaves and bark, which when multiplied by the many trees in an urban setting, produces an impressive retention capacity that can reduce stormwater runoff by 2-7 percent (Tree City USA 2010). In conjunction with other landscaping, an estimated 65 percent runoff reduction can be achieved (Tree City USA 2010), and water retention systems such as vegetation swales, stormwater basins, structural soils, tree pits, and riparian buffers improve runoff reduction even more.

PLACEHOLDER Table 23-2 Watershed Benefits of Urban Forest Cover

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Stormwater Runoff

Trees reduce stormwater runoff by using soil water through transpiration and intercepting rainwater on leaves, branches, and tree trunks, which changes runoff quantity and pollutant loads in several ways. For example, evapotranspiration increases soil water storage potential, tree root systems can increase soil infiltration rates, and interception of rainfall by the canopy reduces the volume and timing of runoff and reduces soil erosion caused by impacts from raindrops.

Structural Soils

Urban areas are challenged by extensive impervious surfaces, damaged soils, and little room for greenspace or for stormwater management facilities. In 2004, a collaboration of researchers from Virginia Polytechnic Institute, Cornell University, and University of California, Davis formed a work group to study the use of trees and structural soils to improve water quality. The system developed and evaluated by the group utilized stormwater BMPs to reduce peak flow, reduce runoff volume, and remove pollutants. The system works by guiding the water into a structural soil retention area beneath the pavement where it is absorbed by soil infiltration and root uptake for tree transpiration. Trees have the potential to develop full canopies that result in increased water interception because the reservoir offers a large root area. Tree roots take up excess nutrients and water in the soil reservoir and can enhance infiltration into the subsoil. Together, trees and structural soils can create a zero runoff site. The group found that with such a system it was possible to distribute stormwater management by taking advantage of the mitigation services provided by urban trees (Xiao and McPherson, 2009). It also created an alternative to detention ponds in urbanized areas.

Quantifying Benefits

Urban trees have multiple co-benefits. For example, a large deciduous canopy tree can intercept 760 gallons of rainfall in its crown annually and aid in reducing runoff of polluted stormwater and flooding, a benefit valued at $6 annually on the basis of local expenditures for water quality management and flood control (U.S. Department of Agriculture Forest Service 1999). Larger potential for canopy interception increases the beneficial effects of tree interception of rainfall, with these effects being greater in larger trees and evergreen trees. An evergreen camphor tree, for example, is estimated to intercept 4,000 gallons annually, providing even greater benefits than a deciduous tree of similar size (U.S. Department of Agriculture Forest Service 1999). In addition, shade from urban forests reduces energy use of city residents by reducing temperatures inside buildings and lowering energy usage rates for interior cooling.

Urban trees also offset greenhouse gas emissions and provide larger-scale climate benefits through their persistent sequestration of carbon in woody material. For example, a study in San Francisco found that urban trees within the city annually sequester an estimated 2,271 tons of CO_2 and indirectly reduce energy plant emissions by 257 tons of CO_2, representing an estimated value of $2.3 million annually (Maco et al. 2003). The combined value of this benefit (e.g., carbon sequestration and offset from reduction in energy use) was estimated at $37,907 annually (Maco et al. 2003). Considering that San Francisco has a mild climate with cool summers, the benefit can be substantially higher in warmer inland cities. There are an estimated 188.5 million urban trees statewide that sequester approximately 414,000 metric tons of carbon annually, i.e., ~ 1.52 million metric tons CO_2 (Novak et al. 2009), so the contribution of urban trees to atmospheric carbon dynamics is substantial.

Recommendations

- Fund urban tree planting in high priority communities, which should yield multiple water use benefits, such as reductions in stormwater runoff and improved water quality, among other benefits such as air pollution mitigation and reduced energy use. The 2010 Forest and Range Assessment (CAL FIRE, 2010a) identified 372 communities as high priority areas for urban tree planting in order to conserve energy or improve air quality.
- Preserve space for large-statured trees in new developments and create such space in developed areas that currently do not have adequate planting sites. Preserving and planting large-statured trees will have a large beneficial impact and improve the extent of urban tree canopy in priority areas. Additionally, improved management of existing urban forest resources will assist in maximizing the benefits of current tree canopy while minimizing long-term costs.
- Encourage and implement BMPs that promote urban forestry for urban stormwater management, which take advantage of benefits offered from tree canopy interception for reduced peak stormwater flows, reduced runoff volume, and removal of pollutants. Use of a variety of stormwater management techniques should be encouraged to maximize urban tree benefits to water resources.

Climate Change

Forests will play an increasingly important role in protecting California's watersheds and associated water supply as the climate warms and precipitation patterns become increasingly variable. Climate change impacts on California's forests that have been measured in the past 100 years include a 10 percent decrease in snowpack, changes in streamflow timing, increased wildfires, and more severe pest outbreaks (California Department of Water Resources 2008).

While susceptible to anticipated changes, proper management of forest habitat provides both climate change adaptation and mitigation benefits. The U.S. Department of Agriculture Forest Service has prepared a resource titled *Responding to Climate Change in National Forests: A Guidebook for Developing Adaptation Options* (U.S. Department of Agriculture Forest Service 2011a). The guidebook is based on the "science-based principles, processes, and tools necessary to assist with developing adaptation options for national forest lands," which can be useful for all forest managers seeking guidance on climate change. One of the key components of successful adaption in forests will be long-term monitoring and research on the various recommendations and policies that are currently promoted and an adaptive management approach that allows incorporation of new information into the existing management paradigm.

Adaptation

Many existing forest management practices can promote resilience to climate change, and, in fact, the best way to ensure successful implementation of high priority actions is to integrate climate adaptation into existing planning and operational processes. For example, strategic forest road management will be important in areas prone to flooding and erosion, which can significantly affect water quality due to sediment transport. Incorporating anticipated climate change impacts and vulnerabilities into road management plans and policies will ensure that priorities are based on the changed conditions under which forest roads will need to be managed in the future. Fuel reduction plans should also incorporate climate change considerations so that the threat of high intensity wildfire situations can be reduced.

Restoration, protection, and proper management of meadows can provide increased water storage and flood protection benefits, which will be very important since increasingly extreme storm events are an anticipated impact of climate change, and precipitation is expected to fall more frequently as rain rather than as snow at lower elevations (California Department of Water Resources 2008). Protection and restoration of headwater streams, including conifer growth in the riparian corridor, could buffer against increasing stream temperature as well as provide habitat connectivity. Healthy forests protect biodiversity, which will be an important buffer against climate change impacts (U.S. Department of Agriculture Forest Service 2011b).

Mitigation

California's forests are carbon sinks, and thus are an important part of climate change mitigation. Sustainable forestry management practices that protect ecosystem services provide greenhouse gas reduction through carbon sequestration as well as other benefits such as water quality protection and energy savings.

Fuel reduction projects, such as mechanical thinning and low severity prescribed fires, entail emissions of GHGs initially, but could reduce the threat of high intensity wildfire and thus prevent even greater emissions at a future date as well protect carbon sequestration capacity of remaining trees in thinned stands. Likewise, managing forest roads uses energy in the short-term, but could result in overall energy savings through reduced sediment transport during heavy rainfall events, thus reducing the energy needed to treat the water downstream.

Urban forestry provides multiple benefits related to climate change mitigation such as decreasing and filtering stormwater runoff, reducing ambient summer air and water temperatures, and carbon sequestration. Careful maintenance of existing urban trees may help offset the “urban heat island” effect and reduce the amount of energy used for cooling in the summer months.

Potential Costs

Meadow Groundwater Storage

Costs of recent meadow restoration projects, including planning and environmental compliance, range from approximately $1,000 to $2,500 per acre, with the higher costs being associated with projects that require construction of new channels using heavy equipment and end-hauled materials (Oehrli and Westmoreland written communication 2008). Maintenance costs for meadow restoration projects are generally very low.

Riparian Forests

No unit cost information is available for riparian forest protection, improvement, or restoration. Actions to benefit riparian forests include appropriate management in both the riparian zone (Van de Water and North 2011; Liquori et al. 2012) and upland watershed improvement projects. Unit costs for upland projects should reasonably represent unit costs for riparian forests.

Vegetation Management

Unit costs for vegetation management on private forest lands in California vary between $20 and $1,200 per acre, depending on the methods used. Manual removal of undesirable species ranges from $70 to $1,200 per acre. Herbicide applications range from $20 to $250 per acre. Herbivory costs range from $500 to $1,200 per acre. Mechanical treatments cost between $800 and $1,200 per acre. Unit costs for vegetation management on National Forest System lands in California are generally higher, ranging from approximately $1,000 to $2,000 per acre (M. Land, USFS, personal communication, 2008).

Fuels/Fire Management

Unit costs for prescribed fire on private forest lands in California are up to $500 per acre for grass and shrub fuels and higher for heavier fuels. Unit costs for fuel reduction projects on National Forest System lands in California ranged from $144 to $2,476 per acre between 2004 and 2006, with an average unit cost of $593 per acre (R. Griffith, USFS, personal communication, 2008).

Road Management

Road upgrading or “storm-proofing” is used to reduce the potential for sediment delivery to stream channels for roads that will remain in service. Recent unit cost estimates for storm-proofing roads on National Forest System lands in the Coast Ranges ranged from $6,520 to $13,580 per mile. Road decommissioning is generally much more expensive due to greater planning, heavy equipment use, and hauling costs.

Illegal Marijuana Cultivation

Mallery (2011) states that the average cost of cleanup for a 10-acre site on public lands involving the use of a helicopter is $5,000. When environmental remediation is included, the cost of site processing doubles, bringing the average to approximately $10,000 per 10 acres. These expenses include helicopter fees, fuel consumption, wages, food, gear (tents, hard hats, gloves, shovels, etc.), trash disposal fees, and other variable costs not including the cost of raids, eradication, or investigations (Mallery 2011). Removal of water storage detention basins requires care to restore original flow patterns, while minimizing sedimentation and changes to perennial and intermittent streamflows. Additionally, the removal of miles of irrigation tubing is one of the most intensive parts of remediation efforts, in terms of time, effort, and cost (Mallery 2011). Agencies such as the U.S. Forest Service have to divert funding from their primary land management functions to finance cleanup efforts because of the high cost cleaning up illegal sites. Law enforcement incurs added costs when needed to address illegal operators before environmental cleanup efforts can take place.

Urban Forestry

The costs of urban tree planting and maintenance can vary greatly with location, site conditions, and the type of tree planted. Total planting cost in California can vary between $45 and $160 per tree. After trees are established, maintenance costs are initially minimal, but begin to accrue after about 10 years when trees start to require pruning and hardscape damage from roots needs to be repaired. These maintenance costs can be reduced by careful selection of trees and planting sites. Additional maintenance costs include inspection, administration, legal claims, disease control, removals, and storm litter cleanup. Maintenance costs are typically higher for trees planted in public spaces, since they require more frequent pruning to avoid interference with power and telecommunications lines, and are also generally adjacent to streets and sidewalks. Average annual tree maintenance costs in California, including planting and maintenance, vary from $13 to $65 annually per tree, with costs higher on public vs. private lands (McPherson et al. 2005).

Major Implementation Issues

The issues described in this section are challenges for implementing one or more of the activities described in the Quantify Benefits section.

Information Needs

Forest management agencies and private timber companies are conducting a number of long-term studies in forested watersheds, including Redwood Creek, Caspar Creek, and South Fork Wages Creek in the northern part of the Coast Ranges; Little Creek in the central part of the Coast Ranges; Judd Creek and Battle Creek in the northern Sierra Nevada; Frasier Peak Creek and Bear Trap Creek in the central Sierra Nevada; and Speckerman Creek, Big Sandy Creek, and the Kings River Experimental Watershed in the southern Sierra Nevada. These studies are providing valuable information about the effects of forest management activities on water quality and quantity, particularly related to timber harvesting, road building, and fuel treatments.

Continued monitoring and additional studies are needed to better understand the effects of forest management activities on water quantity and quality over the wide range of climatic and physiographic conditions found in California. The processes and pathways by which water arrives at the land surface as rain or snow and then reaches stream channels, profoundly affects streamflow regimen, erosion, and contaminant transfer, but these processes are generally poorly understood. Methods for estimating evapotranspiration from different vegetation types need refinement and field verification. Knowledge of groundwater recharge, flowpaths, and storage is limited for mountainous forested watersheds, especially those underlain by fractured rocks. Sources of sediment, transport mechanisms, and the relative importance of erosional processes are not well documented.

Monitoring of streamflow to detect effects of land use is most useful on headwater streams that are not affected by artificial regulation or diversion (MacDonald and Coe 2007). A statewide network of 886 streamflow monitoring stations is operated in California by the U.S. Geological Survey (USGS), but only 214 of these gauges are on streams with more than 50 percent forest cover. Only 31 of these are long-term stations (20 or more years of record) on unregulated and undiverted streams, and very few of these stations include water quality monitoring (C. Parrat, USGS, written communication, 2008). That density is an average of one long-term stream gauge on an unregulated and undiverted stream for every 1,893 square miles of forest in the state, and some of these stations are in danger of closure due to inadequate long-term funding. A higher density of stream gauges and water quality monitoring stations would be helpful for understanding the distribution, timing, and quality of streamflow from forested watersheds across the state.

Coordination Needs

Forest owners and management agencies have disparate management objectives and constraints, and forest ownership boundaries rarely coincide with natural watershed boundaries, which lead to fragmented, uncoordinated activities that are potentially not effective over the entire watershed. For example, USFS funds and staff can generally be used only for work on National Forest System lands, state agencies are frequently prohibited from working on federal lands, and many watershed improvement grant programs are limited to non-federal agencies and organizations. Increased coordination among state, federal, and tribal, private, and non-profit forestry and watershed agencies would provide better opportunities to increase protection of water quality.

A prime example of successful coordination was announced on August 28, 2012 when the Karuk Tribe and the U.S. Forest Service signed a Memorandum of Understanding that will protect the Katimiin Cultural Management Area, near present day Somes Bar, CA. This agreement will restore a sacred landscape by using both Karuk traditional knowledge and management practices and the Klamath National Forest Land and Resource Management Plan, which is administered by the Six Rivers National Forest. The agreement will help prevent wildfires as well as build an understanding and cooperation between cultures, the people, and the environment.

Limited Funding for Forest Watershed Restoration

The rate of progress of meadow restoration, road storm-proofing and decommissioning, and vegetation treatment work is largely limited by available funds. In recent years, appropriated federal funding for watershed programs on National Forests has decreased, and revenue-generating timber sales have declined since the mid-1980s. A large proportion of funding for watershed restoration and fuel treatments is now supplied through state bond measures and grant programs. Some grant programs, however, require non-federal matching funds, which limits the eligibility of projects on federal forest lands.

New sources of funding are needed to continue making progress in watershed restoration. Management of forest resources often results in benefits in water supply, flood control, and flow regulation to downstream communities, whose residents, in most cases, are unaware of these benefits of upstream forest management. With an appropriate outreach effort, these communities, which do not usually contribute to the funding of upstream forest management, might be willing to contribute if the costs and benefits could be demonstrated to them.

Regulatory Requirements

Forest management actions that affect the amounts or timing of streamflow, such as attenuating flood peaks and increasing infiltration to groundwater, may be viewed as threats to existing appropriated rights, and could potentially result in water rights litigation. Surface waters may be appropriated by landowners and other users and these appropriators have legal rights to the water they are permitted to divert. In most cases, reduced flood peaks will not result in less available water for downstream users, but water rights may need to be resolved for any additional water made available by meadow restoration, vegetation management, and fuels treatment.

Harvesting of timber on non-federal lands must comply with the California Forest Practices Act and Rules, the California Environmental Quality Act (CEQA), and other state regulations. Timber harvests and other vegetation and fuel management projects on federal lands are analyzed following NEPA guidelines, and appropriate BMPs are determined for protection of water quality. Federal and non-federal timber harvests, vegetation management, and fuels projects are also regulated by the Regional Boards through Waste Discharge Requirements (WDR) or Waivers of Waste Discharge Requirements.

Duplicative environmental reviews and inconsistencies in regulatory requirements among agencies make permitting of vegetation management projects difficult, increase costs, and slow the rate of progress of watershed restoration efforts. For example, Waste Discharge Requirement stipulations and conditions for Waivers of Waste Discharge Requirements vary among the nine Regional Water Quality Control Boards. In some situations, projects require more than one permit related to water quality, sometimes from as many as three different agencies. A streamlined "one-stop shopping" approach would expedite projects and lower implementation costs.

Prescribed fires, which are being more widely used for vegetation management, are regulated by the California Air Resources Board (ARB) and local air pollution control agencies and can only be conducted on days approved for burning on the basis of air quality conditions. The USFS is currently working cooperatively with the Regional Air Quality Control Boards to increase opportunities for prescribed burning. Additionally, the ARB, along with the U.S. Environmental Protection Agency (USEPA) and local air quality management districts, regulate biomass power plants that often utilize woody material generated by vegetation management projects.

Recommendations

The following recommendations are intended to address the issues identified in the previous section.

Monitoring and Research

Long-term monitoring is needed to understand hydrologic changes resulting from climate change and management actions, and more data collection stations are needed to accurately determine how changes in hydrology and water quality are related to climate change and forest management activities:

1. Additional stream gauges are needed throughout the forested regions of California to adequately represent the existing range of hydroclimatic and geologic conditions. In particular, gauges would be helpful on small (first to third order) reaches on unregulated and undiverted streams, in both managed and pristine watersheds.
2. Additional precipitation stations and snow courses are needed to increase the accuracy of determinations of climatic trends and evaluations of effects of management activities.
3. Additional water quality and sediment monitoring stations are needed to quantify the effects of climate change and forest management activities on surface water quality.
4. Additional long-term monitoring wells would be useful for understanding groundwater resources in forested watersheds.

Forest management for water resources could benefit from additional research on:

5. Effectiveness of BMPs in protecting beneficial uses of water.
6. Effects of vegetation and fuels management on soil moisture, groundwater recharge, and streamflow. More quantification of both the short- and long-term effects of prescribed fire on soil and water nutrient status is needed to determine the most beneficial and most ecosystem friendly return interval as a management strategy. Determination of the impacts of burn frequency on soil and vegetative properties that influence infiltration, percolation, surface runoff, and groundwater discharge would also be advantageous (Tahoe Science Consortium 2007).
7. Effects of wildfires and wildfire control measures on water quantity, water quality, and aquatic organisms.

8. Role and magnitude of groundwater storage in mountain meadows and its effects on streamflow regulation, and of the potential benefits of meadow restoration for water quantity and quality.
9. Sediment sources and erosion processes in managed and unmanaged forested watersheds.
10. Effects of riparian forests in maintaining stream temperatures and cycling nutrients.
11. Effects of urban trees in reducing non-point source pollution.

Coordination

Actions that would provide for better multi-party coordination of forest management, including communication between downstream water users and upstream forest managers, residents and workers, include:

12. Involvement of forest managers in integrated resource water management plan development.
13. Determination of mutually agreeable objectives for forest and meadow protection and restoration in terms of land area and timelines, and commitments from forest managers to meet these objectives.
14. Expanded authority and interagency agreements to allow federal, state, and non-governmental agencies to share expertise, staff time, and funding across jurisdictional boundaries for the purposes of watershed and water quality protection and improvement.
15. Develop a public education campaign directed at water users and communities in the Central Valley, Bay Area, and Southern California to increase support of forest management funding for improvement of water resources, particularly related to vegetation management.
16. Resolve water rights issues related to restoration of forested watersheds, and develop mechanisms for marketing of additional water made available by restoration projects.
17. Expand the scope of state water resource development and conservation measures to include headwaters areas of the state and urban forestry in metropolitan areas.
18. Increase eligibility of federal agencies for grant programs, and allow federal funds and in-kind services to be used as grant matches.

Regulatory Requirements

The water quality management plans developed by the State Water Resources Control Board and forest management agencies can be revised to address concerns with impaired water bodies, while at the same time providing consistency and cost-effectiveness. Regulatory workloads can be reduced by combining environmental compliance into fewer streamlined procedures that would apply to all projects that meet criteria for low risk of adverse watershed effects or net beneficial water quality effects.

The following recommendations are directed at regulatory oversight of forest water resources:

19. Revise forest management agency water quality programs as necessary to identify, prioritize, and repair existing pollution sources, improve BMPs, and modify monitoring programs.
20. Incorporate existing Management Agency Agreements between the State Water Resources Control Board and forest management agencies into cost-effective and consistent regulatory mechanisms compliant with current state law.
21. Deregulate low-risk noncommercial vegetation and fuels management projects that reduce the risks of catastrophic wildfires and therefore have net beneficial effects on water quality.
22. Complete a water quality management plan for the U.S. Bureau of Land Management.
23. Change the State Water Resources Control Board's Water Quality Control Policy for Addressing Impaired Waters to incorporate Category 4B of U.S. Environmental Protection Agency's

Integrated Reporting Guidance, thereby allowing water quality management programs of other entities to be used to attain water quality standards in 303(d)-listed impaired waters in lieu of adopting total maximum daily loads (TMDLs) and duplicative TMDL implementation plans.

Beneficial Forest Management in Areas with Commercial-Scale Marijuana Cultivation

24. A combination of innovative prevention and enforcement approaches are needed to gain control over commercial-scale marijuana operations in California. Google Earth imagery and other remote sensing tools, such as infrared heat imaging, are now available to allow for increased site detection and information gathering. Even with these tools, however, new law enforcement strategies, a commitment to long-term investment of adequate resources, and large-scale changes in public policy are needed to change the current situation (Mallery 2011).
25. Education is also an important component of preserving public lands for public benefit, such as the production of abundant, clean water. Major knowledge gaps exist between the public, politicians, and law enforcement agency personnel (Mallery 2011), although several recent newspaper stories, blog postings, and PowerPoint presentations to regulatory agencies and others have heightened general awareness of this threat to water quality in California (Dawson 2011). The effects of marijuana cultivation on water quality and fisheries resources were part of a state legislative hearing in Sacramento in February 2012, with discussion of possible legislative action. Water quality and fisheries protection are two essential components of a successful California Water Plan.
26. Commercial-scale marijuana cultivation on public and private lands is producing significant environmental problems. There are possible solutions, but without essential changes in law enforcement strategies and public policy, it is a problem that can be expected to continue into the foreseeable future (Mallery 2011).

Special Author's Note

The forest management chapter, a new feature of the Water Plan, was first proposed by Melvin Carmen of the North Fork Mono Tribe at a special tribal regional plenary session. He recounted from his personal history the changes in watersheds directly linked to forest practices. Melvin monitored the chapter development, led by the United States Department of Agricultural Forest Service in partnership with DWR, CAL FIRE, the SWRCB, and the University of California, Merced, and participated in the public workshops. Melvin passed away in 2009 without seeing the final chapter. This chapter is dedicated to Melvin.

Forest Management in the Water Plan

[This is a new heading for Update 2013. If necessary, this section will discuss the ways the resource management strategy is treated in this chapter, in the regional reports and in the sustainability indicators. If the three mentions aren't consistent, the reason for the conflict will be discussed (i.e., the regional reports are emphasizing a different aspect of the strategy). If the three mentions are consistent with each other (or if the strategy isn't discussed in the rest of Update 2013), there is no need for this section to appear.]

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Table 23-1 Acres of Forest Land by Ownership in California

Landowner	Acres [a]	Percentage
Private non-corporate	8,448,000	22.5
Private corporate	4,719,000	12.6
County	330,000	0.9
State	726,000	1.9
USFS [b]	20,166,000	53.7
BLM	1,650,000	4.4
NPS	1,287,000	3.4
Other federal	231,000	0.6
Total	**37,557,000**	**100.0**

Source: California Department of Water Resources 2011

Note: [a] Acres reported are “real” forest rather than total ownership.

Source: Christensen, et al. 2008.

[b] Source: USDA Forest Service 2008.

Table 23-2 Watershed Benefits of Urban Forest Cover

Benefit	Description
Reduce storm water runoff and flooding	• Trees intercept rainfall in their canopy, reducing the amount of rain that reaches the ground. A portion of this captured rainwater evaporates from tree surfaces. • Trees take up water from the soil through their roots, which increases soil water storage potential and lengthens the amount of time before rainfall becomes runoff. • Trees promote infiltration by slowing down runoff and by increasing soil drainage in the root zone. The addition of organic matter (e.g., leaves) also increases storage of water in the soil, further reducing runoff. • Forested land produces very little runoff, which can reduce downstream flood flows that erode stream channels, damage property, and destroy habitat.
Improve regional air quality	• Trees absorb pollutants such as nitrogen dioxide, carbon monoxide, ozone, and particulate matter from the atmosphere. • Trees reduce air temperature, which reduces formation of pollutants that are temperature dependent, such as ozone. • Trees indirectly improve air quality by cooling the air, storing carbon, and reducing energy use, which reduces power plant emissions.
Reduce stream channel erosion	• Trees growing along a streambank prevent erosion by stabilizing the soil with root systems and the addition of organic matter.
Improve soil and water quality	• Trees prevent erosion of sediment by stabilizing the soil, and by substantially dispersing raindrop energy. • Trees take up stormwater pollutants, such as nitrogen, from soil and groundwater. • Forested areas can filter sediment and associated pollutants from runoff. • Certain tree species break down pollutants commonly found in urban soils, groundwater, and runoff, such as metals, pesticides, and solvents.
Provide habitat for terrestrial and aquatic wildlife	• Forests (and even single trees) provide habitat for wildlife in the form of food supply, interior breeding areas, and migratory corridors. • Streamside forests provide habitat in the form of leaf litter and large woody debris for fish and other aquatic species. • Forest litter such as branches, leaves, fruits, and flowers form the basis of the food web for stream organisms.
Reduce summer air and water temperatures	• Riparian forests shade the stream and regulate summer air and water temperatures, which is critical for many aquatic species. • Trees and forests shade impervious surfaces, reducing temperature of stormwater runoff, which can minimize the thermal shocks normally transmitted to receiving waters during storms.

Source: Watershed Forestry Resource Guide - Urban Watershed Forestry 2008.